EGUN Ion Optics Study of the Fermilab Preac

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SUMMARY

This report presents the results of initial EGUN calculations of the ion beam optics of the Fermilab preac. Injection into the preac of an 18 keV H^- beam is studied under the assumptions of full voltage acceleration (to about 780 keV) as well as reduced voltage operation. The beam characteristics are compared with a proton beam originating from a plasma at the beginning of the preac.

1. Overview of this report

This report is largely the presentation of graphic outputs generated from doing the EGUN calculations. To make it easier to follow, a short description is given for each section, followed by the illustrations. In all calculations involving the H^- beam a current of 50 milliamps was used.

2. Setting up the EGUN calculation

In order to set up the EGUN optics calculation a definition of the problem boundary is required. The blueprints of the preac electrodes were xeroxed onto graph paper and the boundary was entered into the input file in the usual way. A copy of the input map is shown on the following page. A few problems associated with the input should be noted. The electrodes were too thin to enter them in smoothly – they were smaller than the grid size of the graph paper used. This had the effect of slightly increasing the aperture of the electrodes. Near the upper edge of the boundary of the problem the electrodes were squared off to allow for ease in calculating the Neumann boundary for the problem at that point. The first problem can be cured by going to a finer grid size, but it is doubtful whether any significant change in the optics would result. Lastly, the first and last apertures were considered to be equipotential surfaces with the electrodes surrounding them. This may have had an effect on the results of the calculation, and should be checked during future calculations.

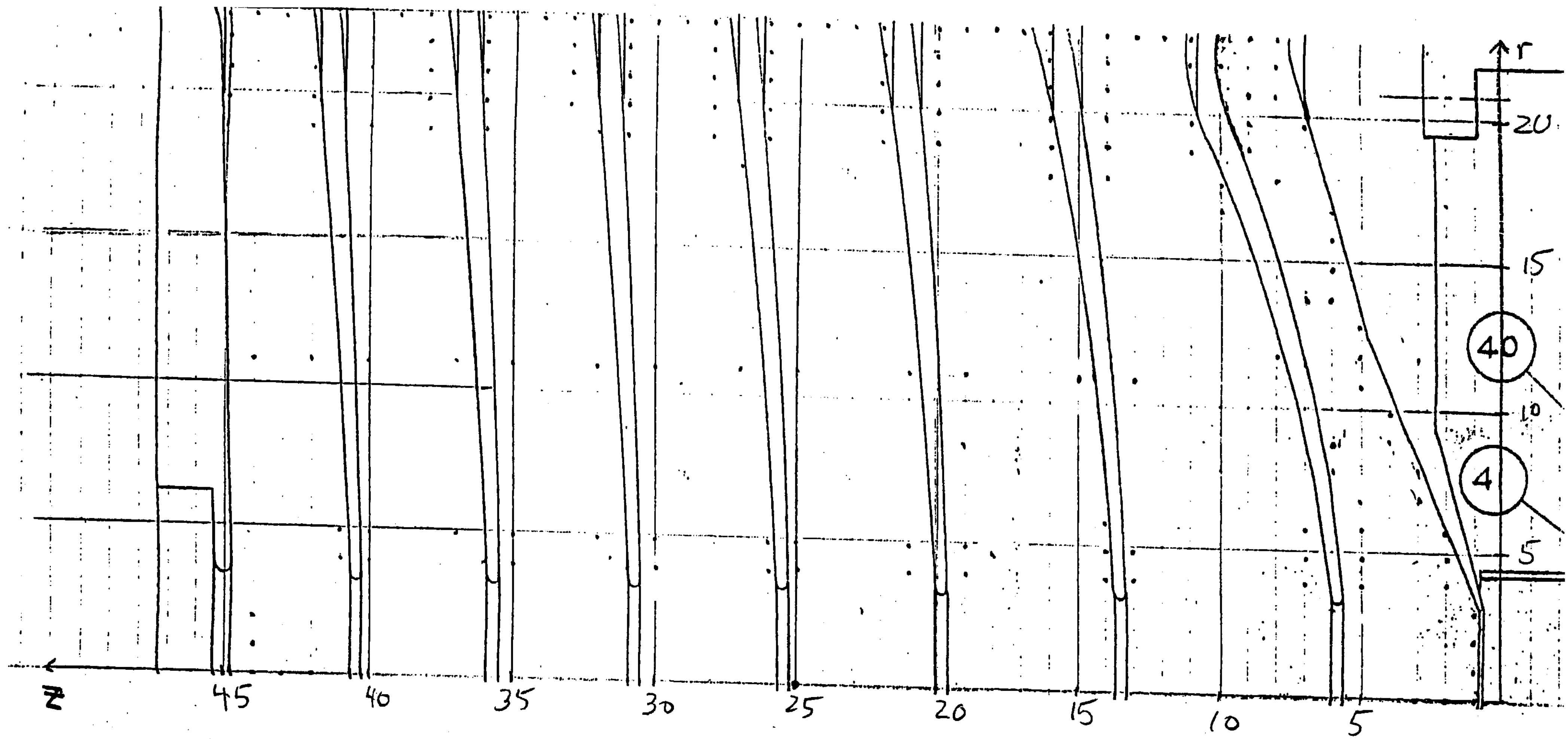
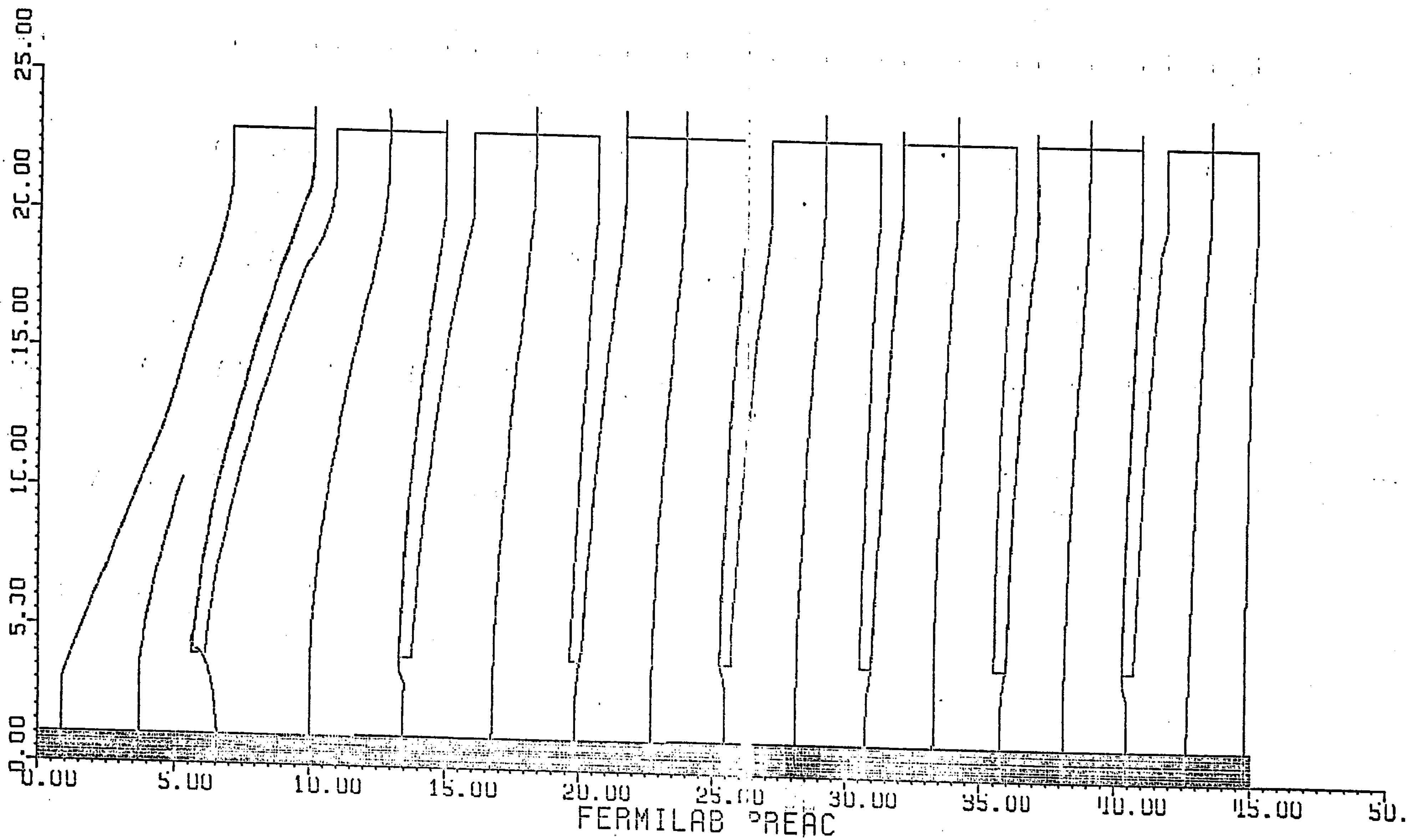


Figure 1 – EGUN boundary set up points.

3. Initial runs of the problem

The first runs of the problem were done under the assumption of zero divergence of the beam as it entered the preac, and did not include the finite beam emittance. The beam was assumed to enter the preac as a round beam of radius 0.5 centimeters. Next, the initial divergence of the beam was included in the calculation. The divergence was assumed to be cylindrically symmetric. Results of the EGUN study for these early tests are presented on the following pages. Studies were done under the case of full acceleration of the beam in the preac (760 keV) as well as lower voltage operation (200 keV).

Figure 2 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have no initial divergence and no emittance.



radially symmetric

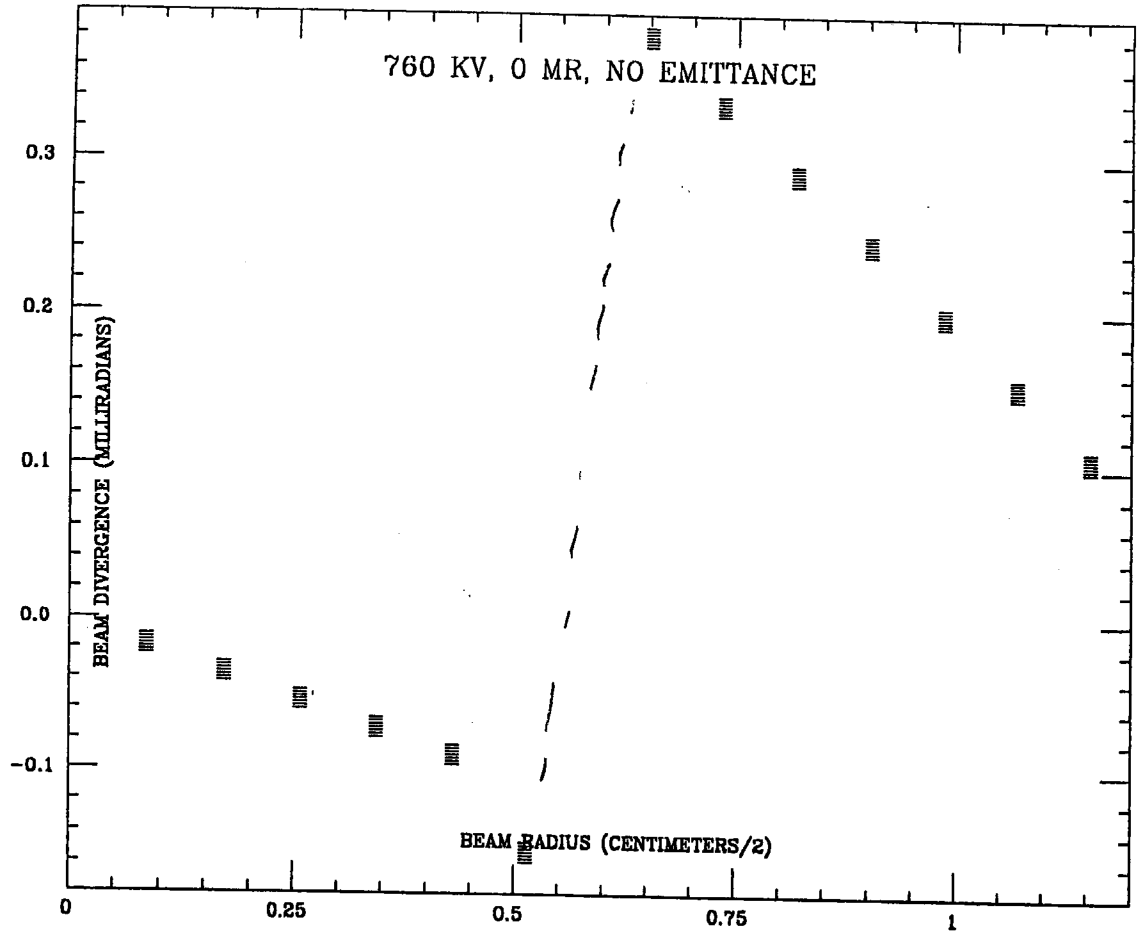


Figure 3 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have no initial divergence and no emittance.

4. Including the effects of finite emittance in the calculations

The EGUN input for including finite emittance effects is the temperature of the cathode in Kelvin. Thus, the emittance of the initial beam must be converted to Kelvin. The normalized emittance of the Fermilab H^- beam is estimated to be about 0.06 π cm-mr. For an 18 keV beam the quantity $\beta\gamma$ is about 0.006. Thus the beam emittance as it enters the preac is about 10 π cm-mr. The lattice beta function at the input to the preac is is given by the expression $(\pi r^2)/\epsilon$, or 1/10 of a centimeter in this case. Thus, the thermal angular spread in the beam, given by

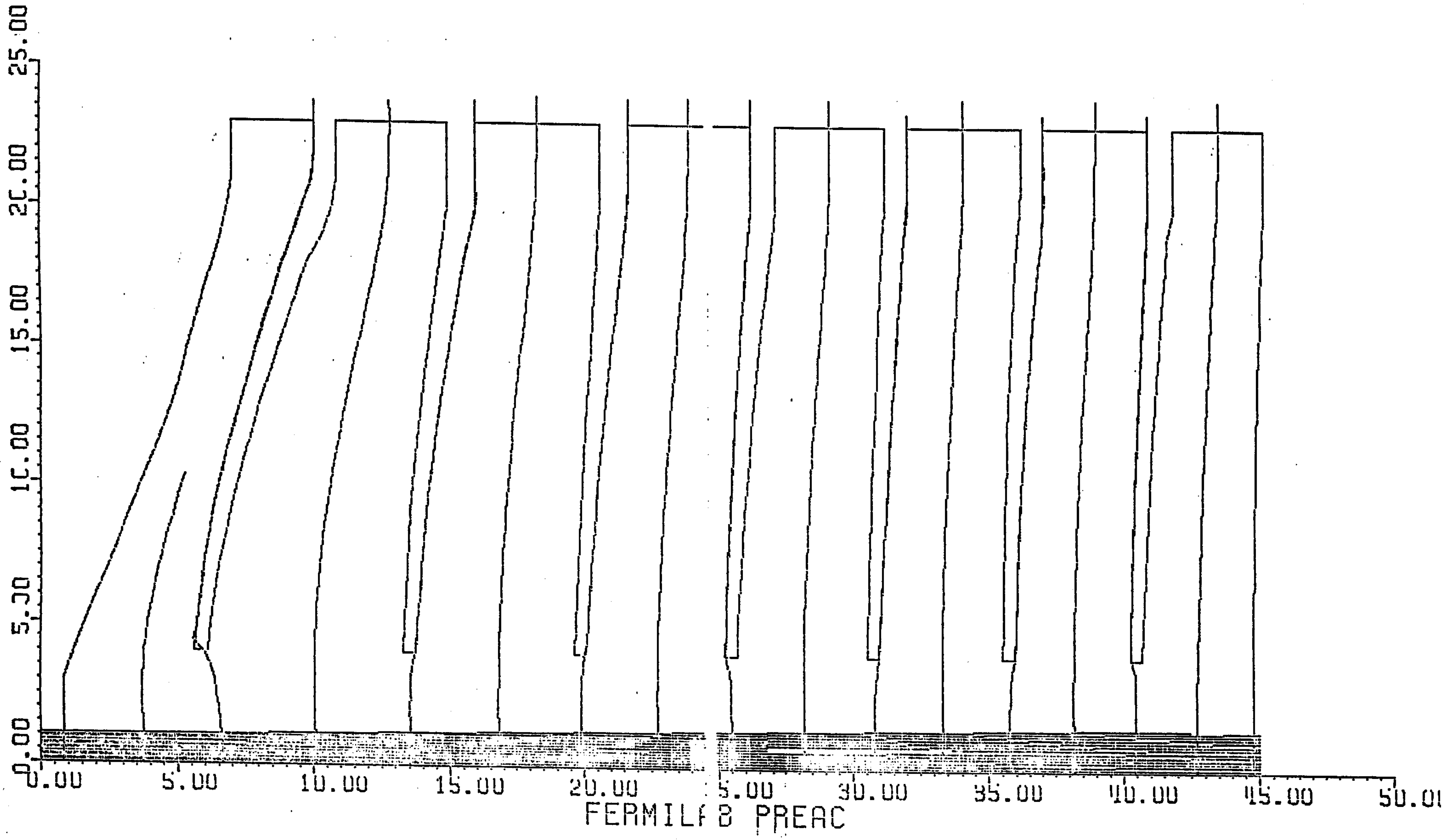
$$\theta = \left(\frac{\epsilon}{\pi\beta_{lattice}}\right)^{1/2}$$

is 10 milliradians. This leads to a transverse velocity of $v_{perp} = \gamma\beta\theta c$ of 18,000 m/s. The energy corresponding to this velocity, $E = (1/2)m_p v^2$ is 3 eV, or 35,000 Kelvin. Since this corresponds to a six sigma point in the distribution, the input temperature to the EGUN code is about 7,000 Kelvin.

The next few pages contain the EGUN output for the preac ion optics studies including the effect of finite emittance.

$\epsilon \ldots \sqrt{6}/e$

Figure 4 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have no initial divergence and no emittance.



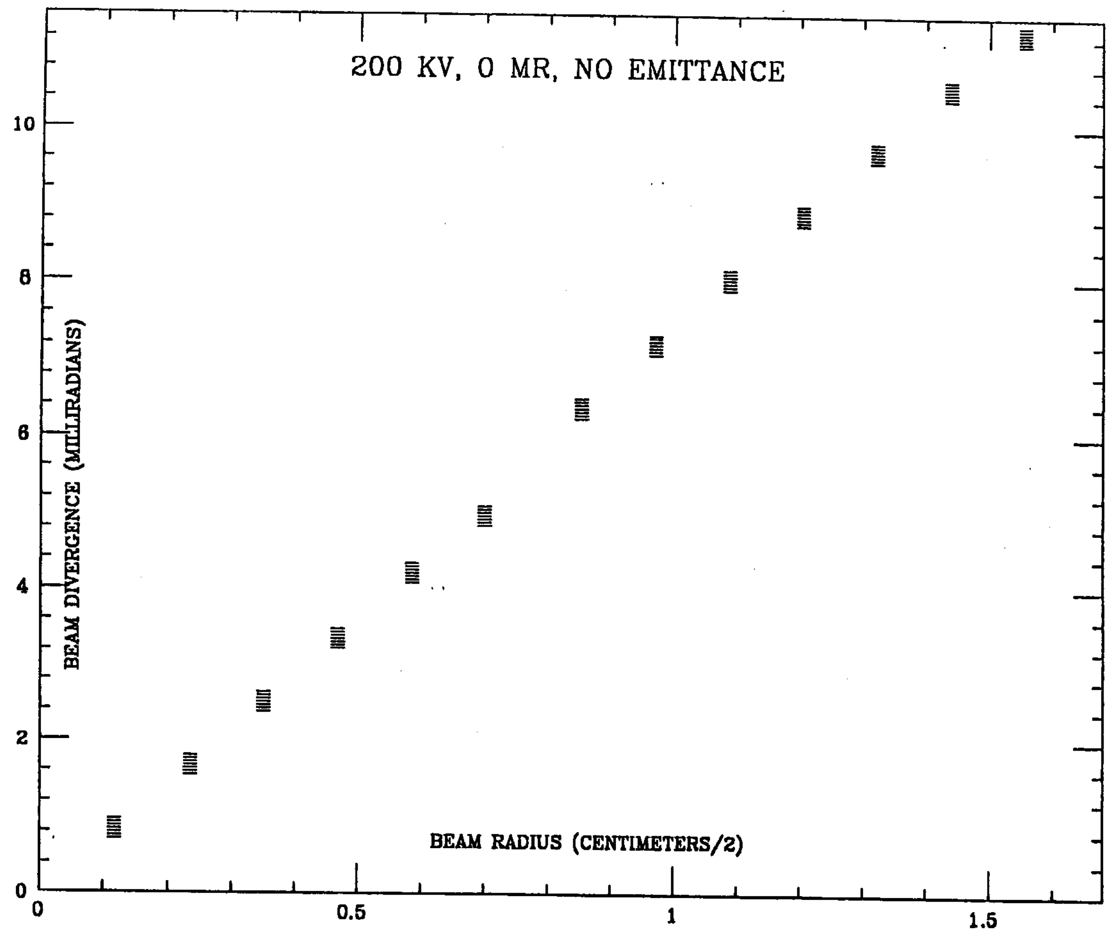
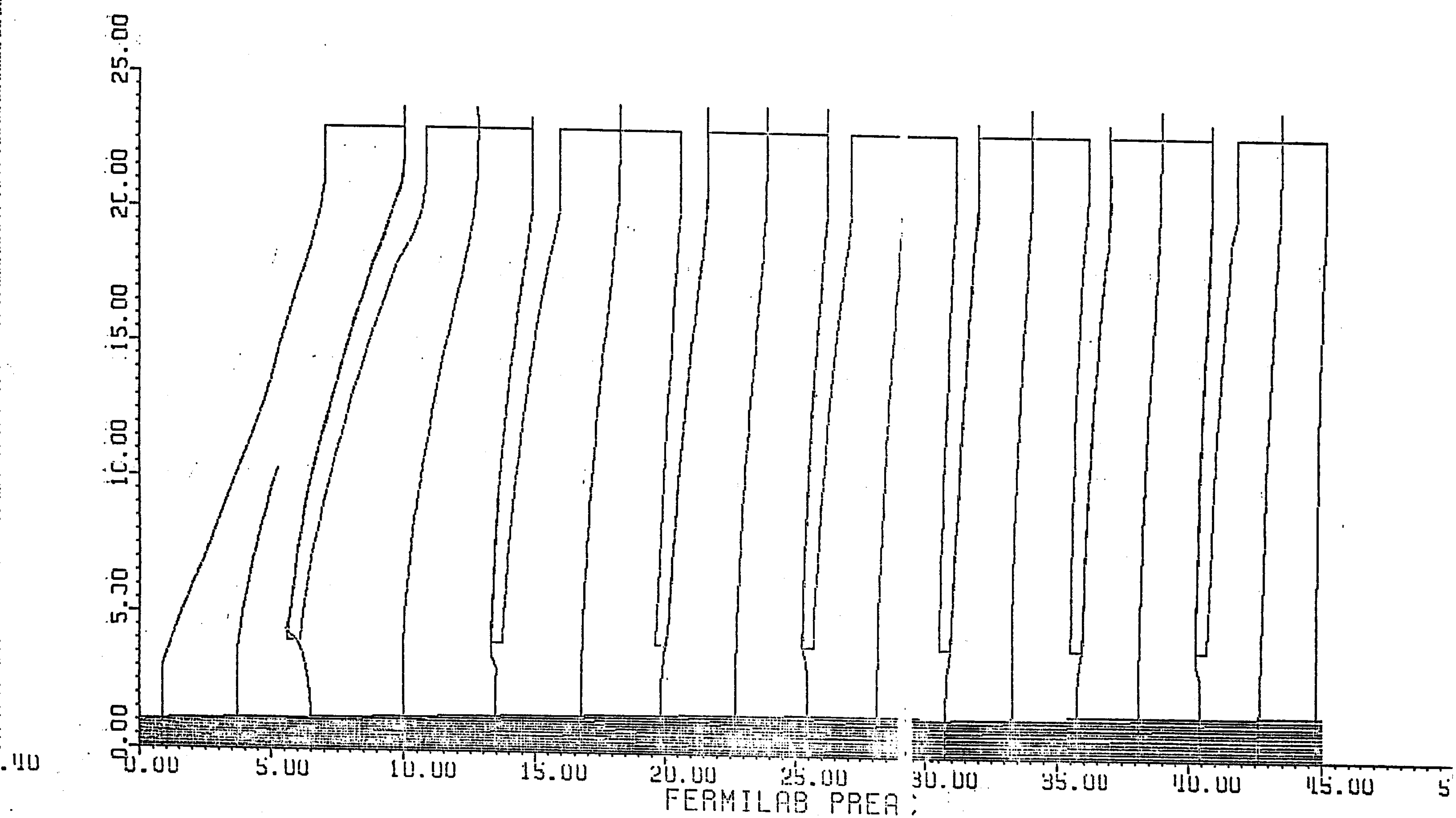


Figure 5 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have no initial divergence and no emittance.

Figure 6 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and no emittance.



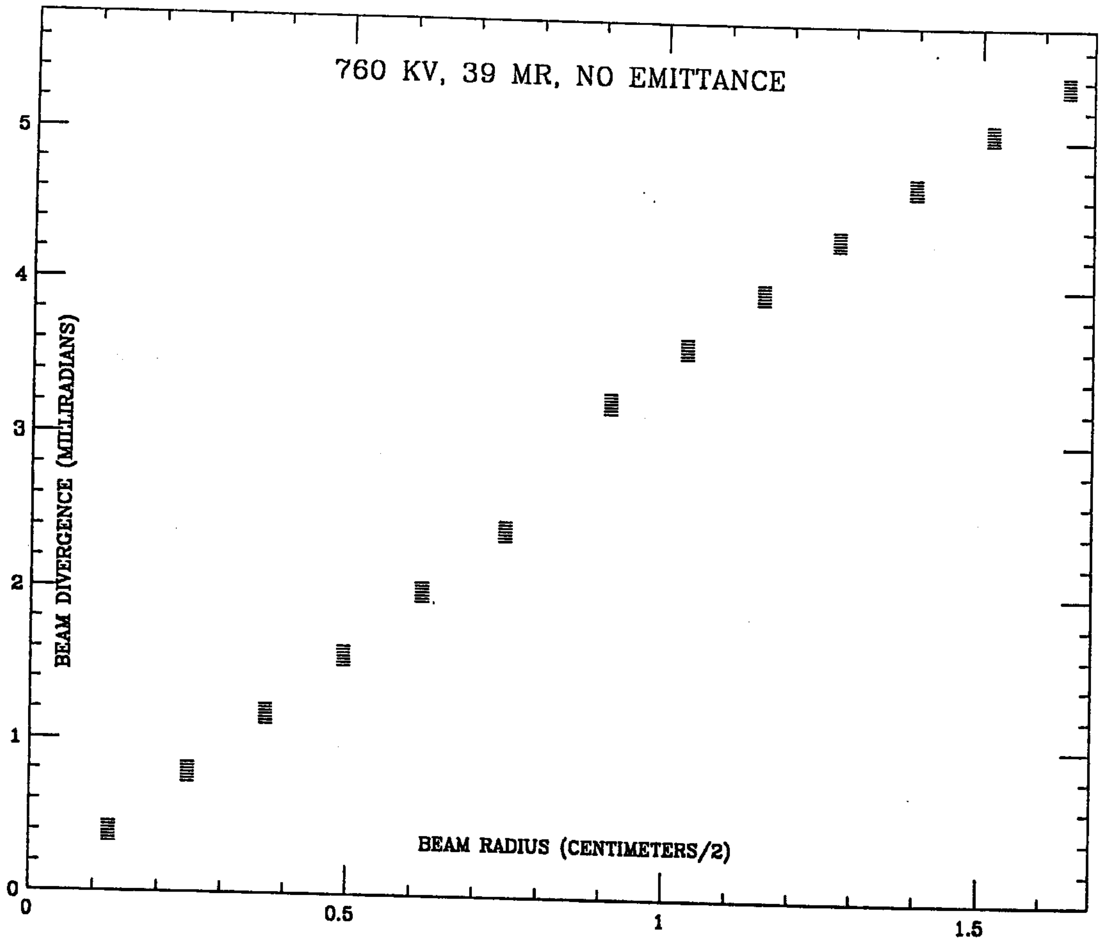
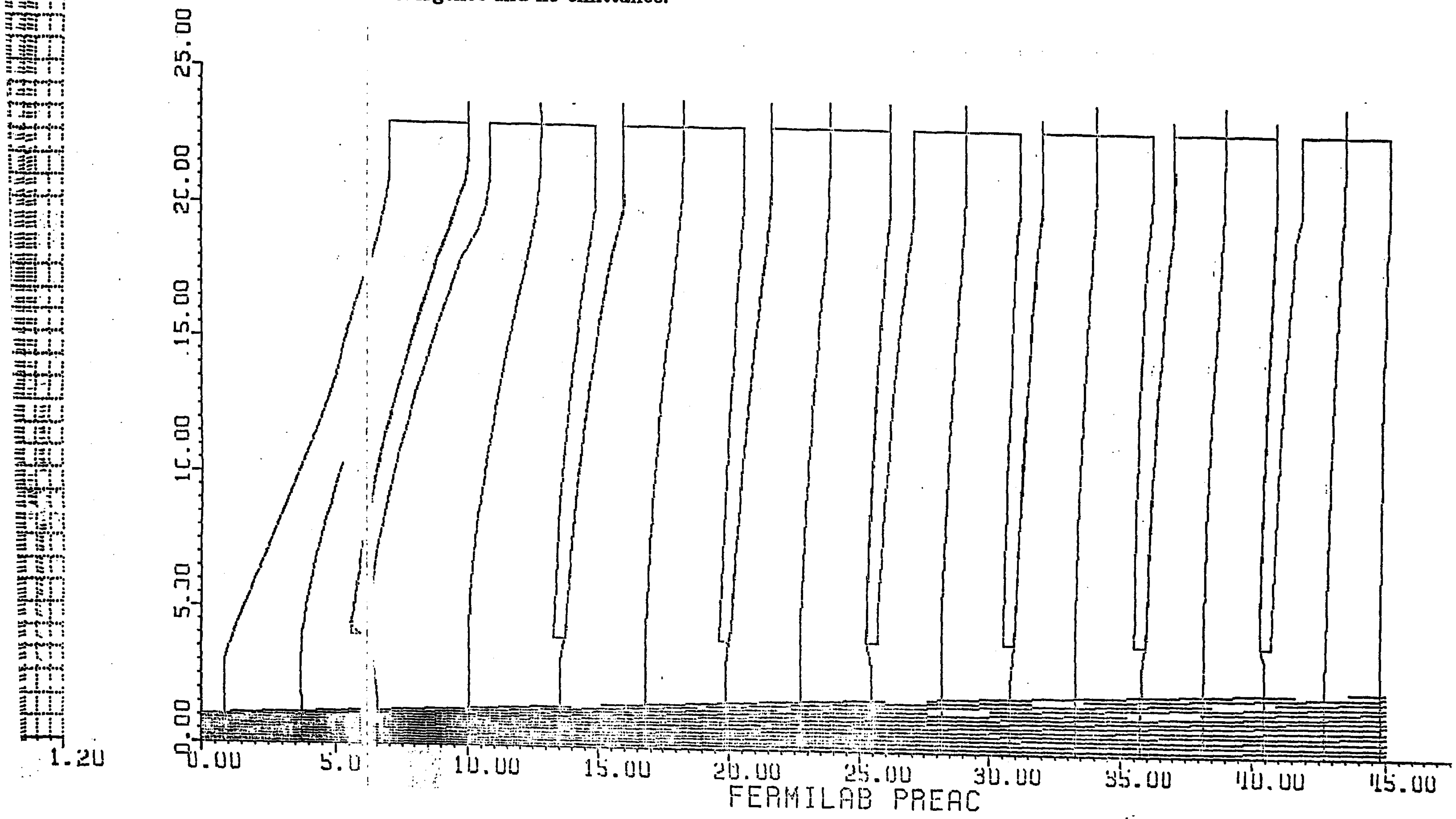


Figure 7 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and no emittance.

Figure 8 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and no emittance.



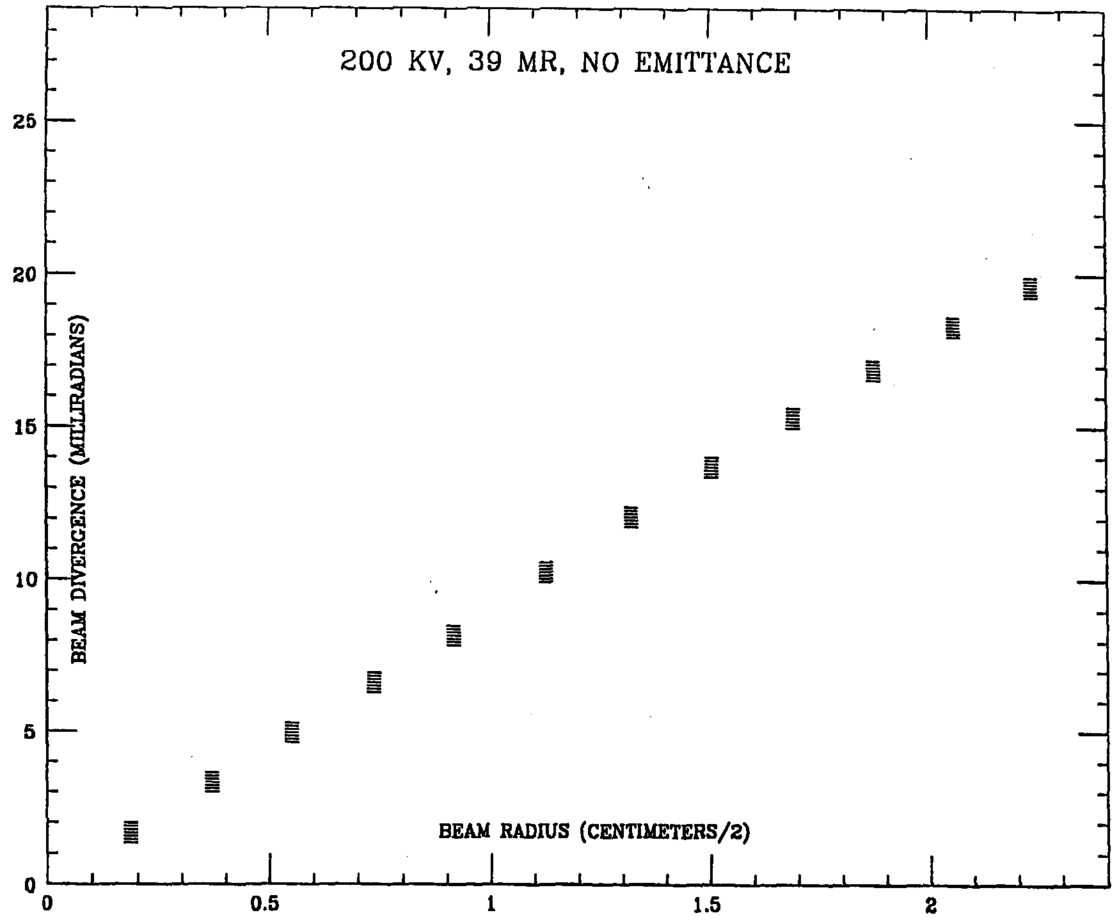
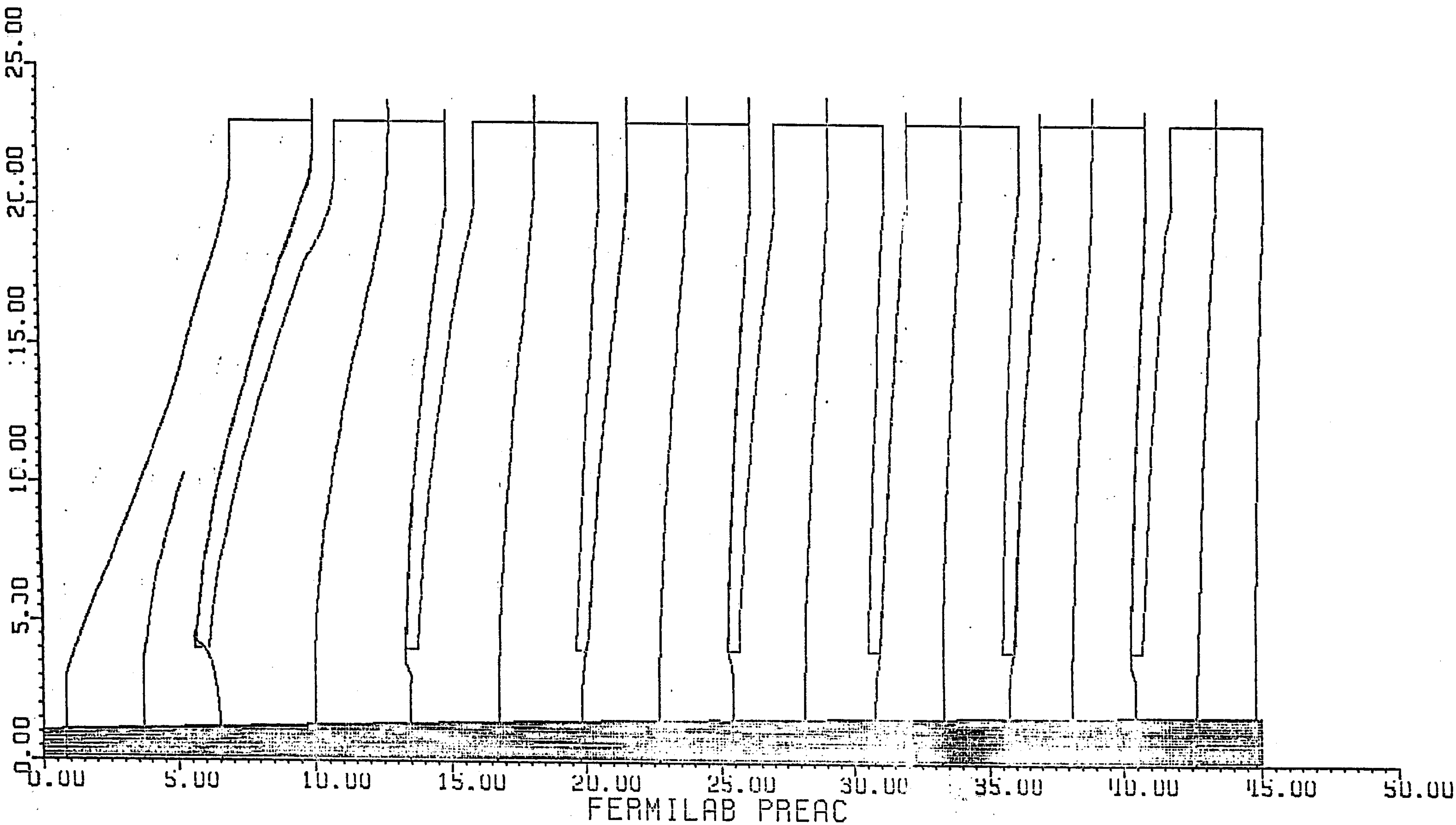


Figure 9 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and no emittance.

Figure 10 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.



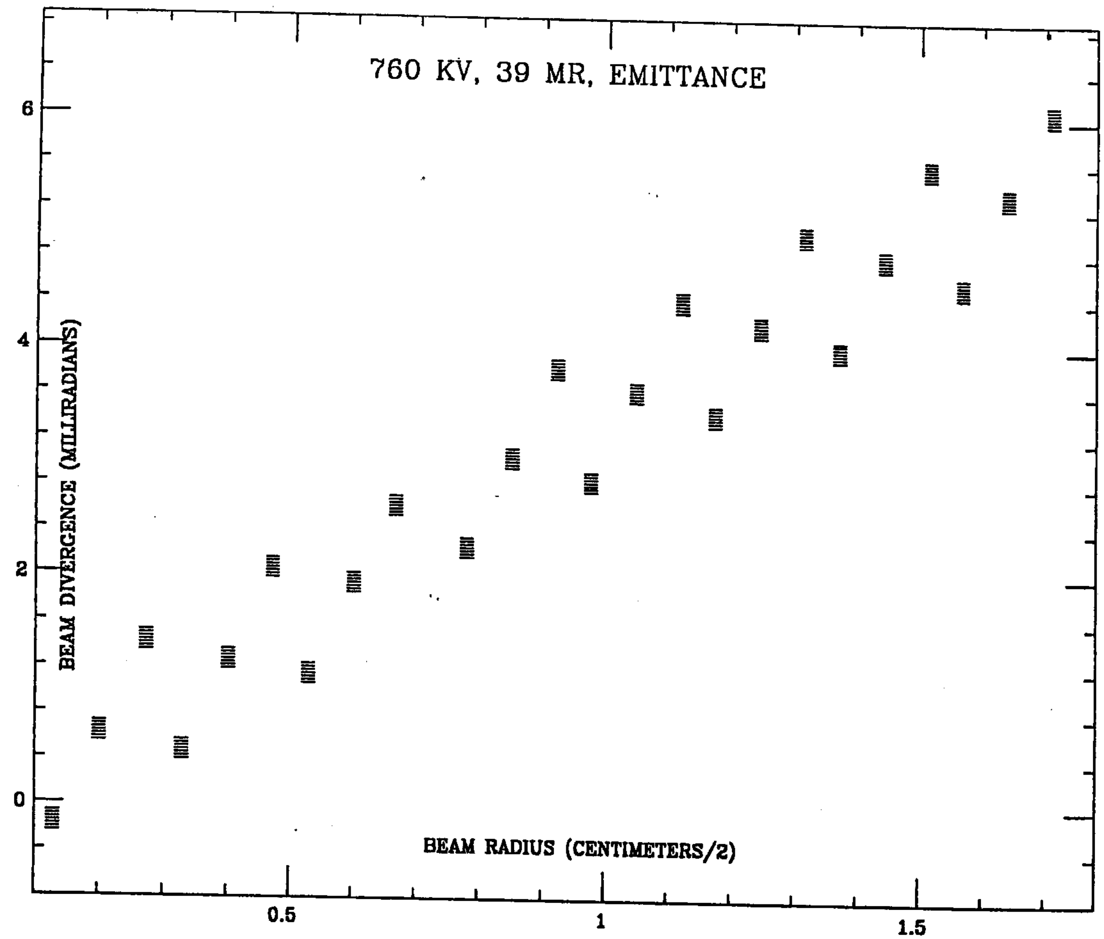
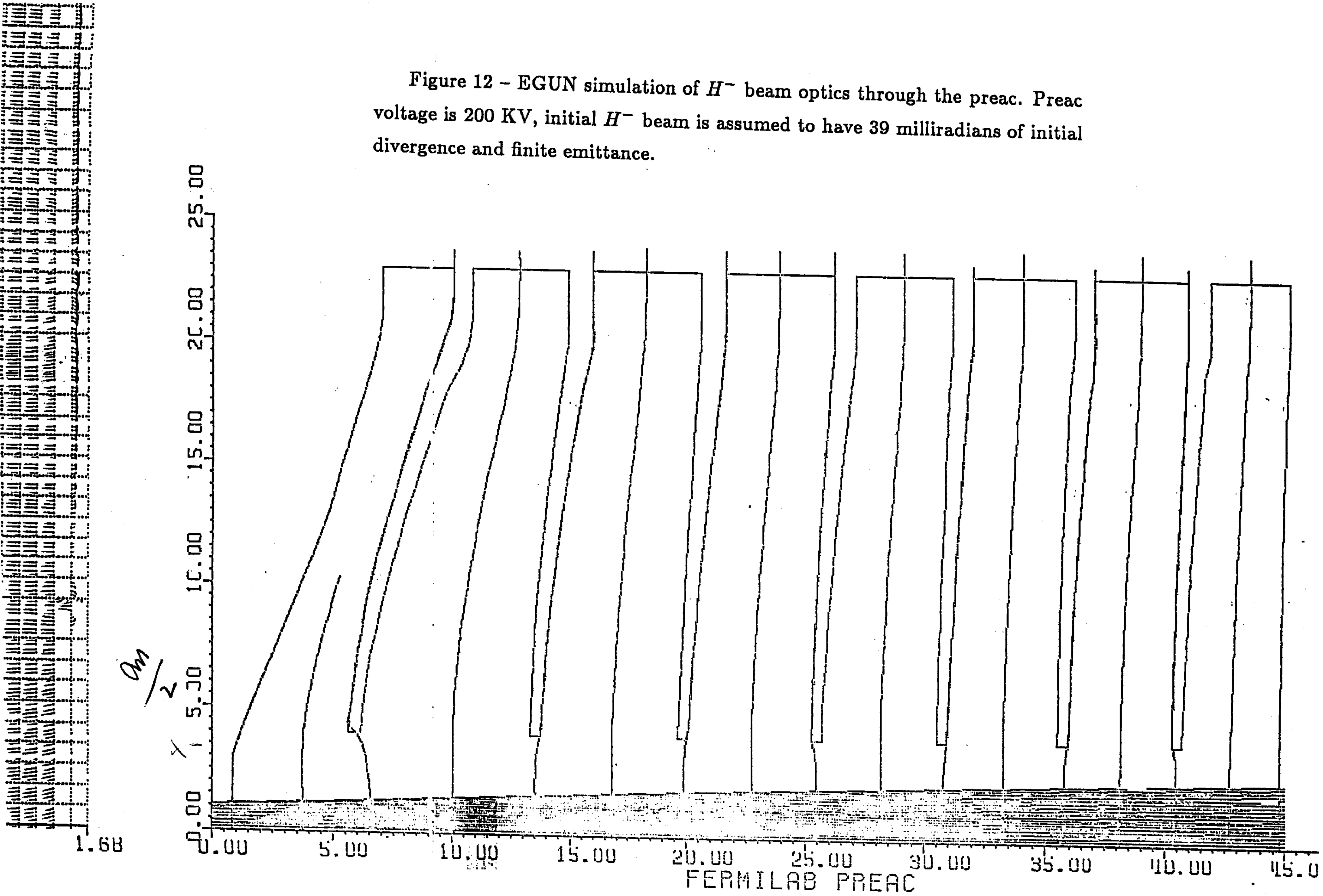


Figure 11 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.

Figure 12 – EGUN simulation of H^- beam optics through the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.



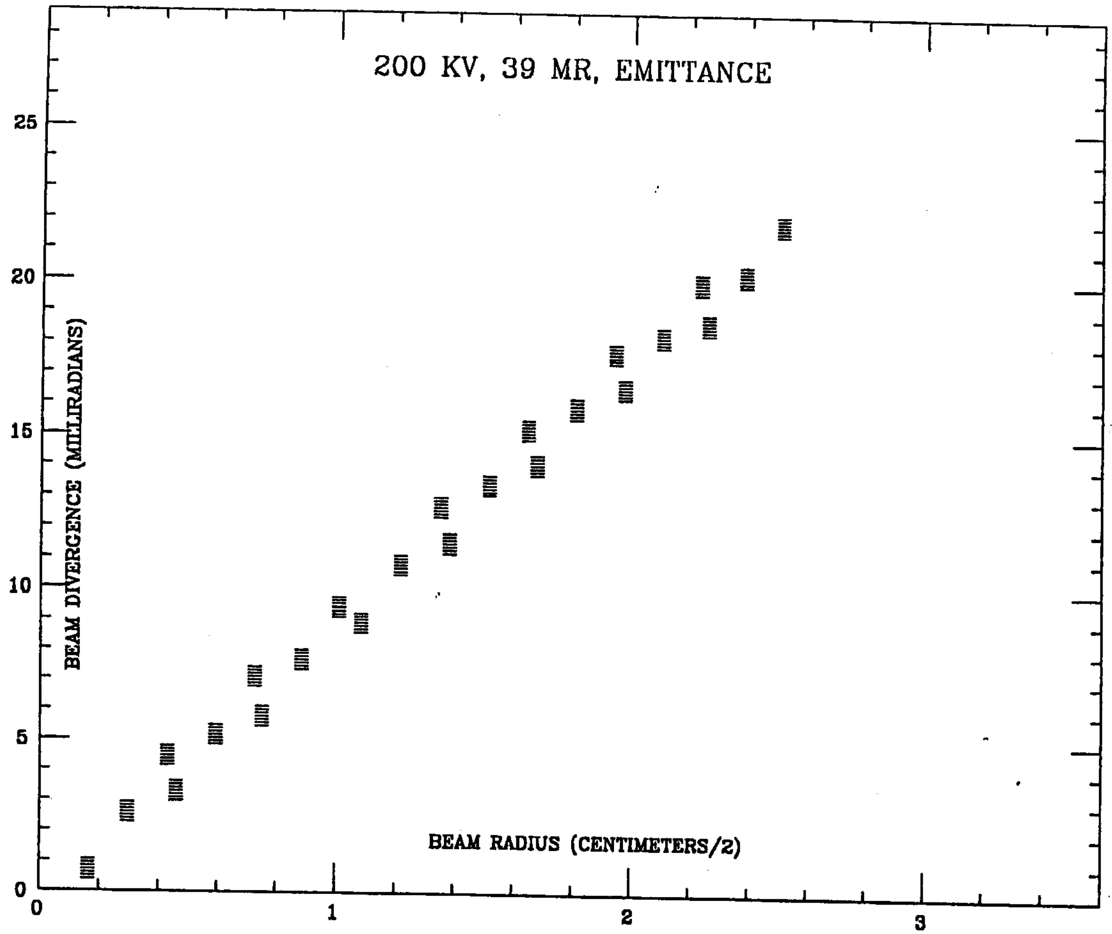
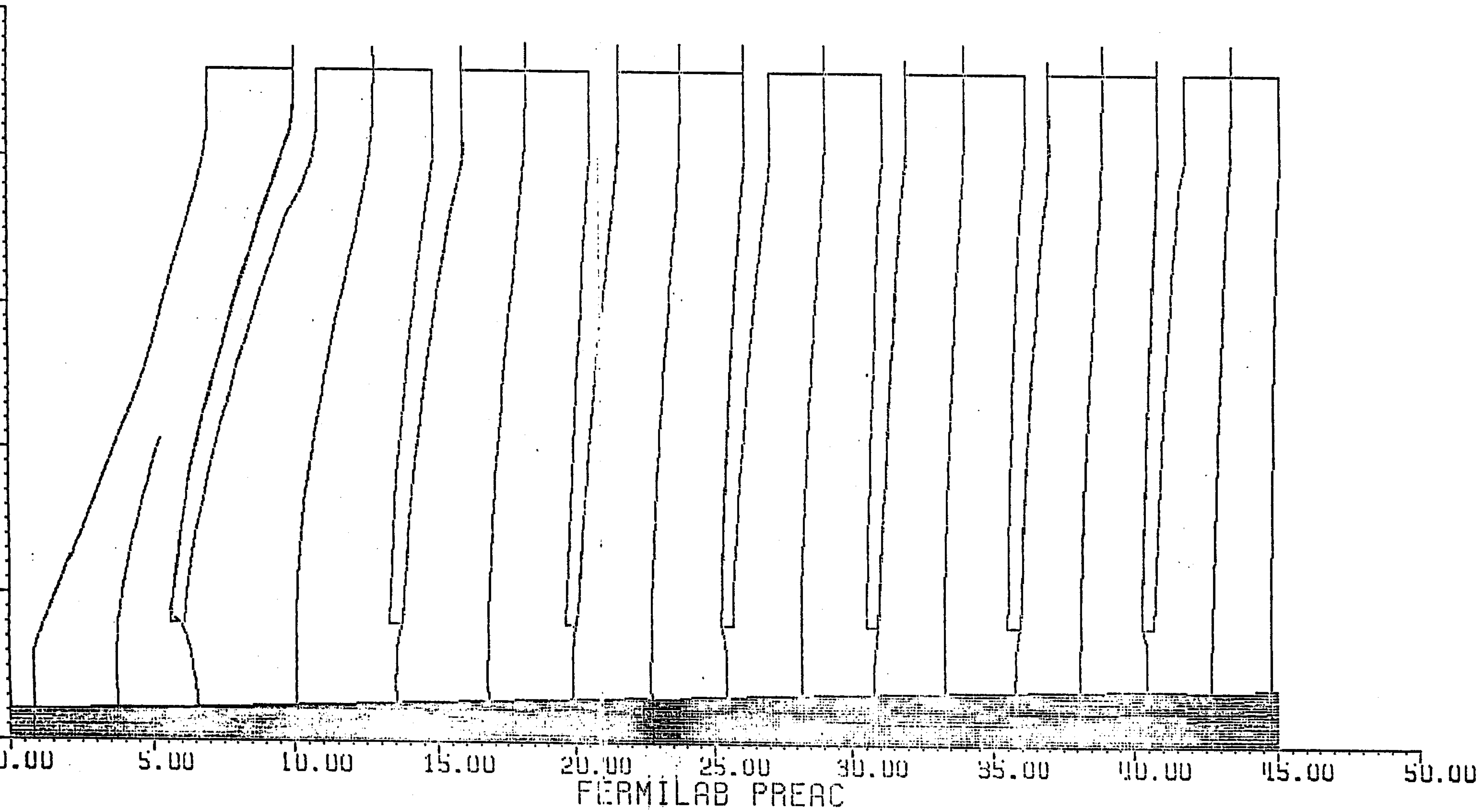


Figure 13 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.

5. Comparison with a thermally emitted beam

It is my understanding that the preac was originally designed to operate with a source of thermal protons near its entrance aperture. Thus, to test the optics matching with elements downstream, I used a thermal beam source as an input to the problem. The proton beam has a current of 300 milliamperes, and is assumed to have an initial radius of 0.5 cm., and an emittance equal to that of the H^- beam studied above. The next page presents the results of the EGUN study done on the proton beam, while the last page of this report presents the phase space plot of the thermally emitted beam at the exit of the preac, as well the phase space plots of the two H^- cases studied before. It is seen that the thermally emitted phase space plot falls between the two studied cases.

Figure 14 – EGUN simulation of thermally emitted H^+ beam optics through the preac. Preac voltage is 760 KV, initial H^+ beam is assumed to have a current of 300 milliamps.



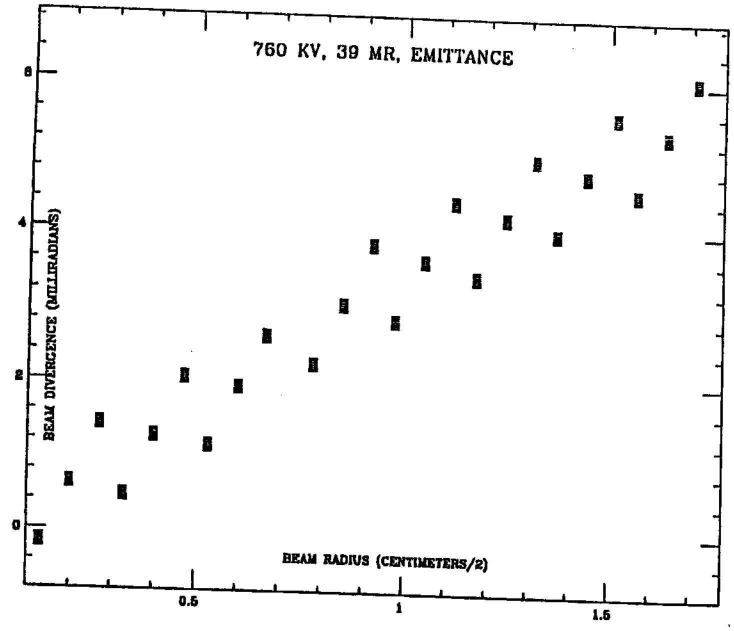


Figure 11 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 760 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.

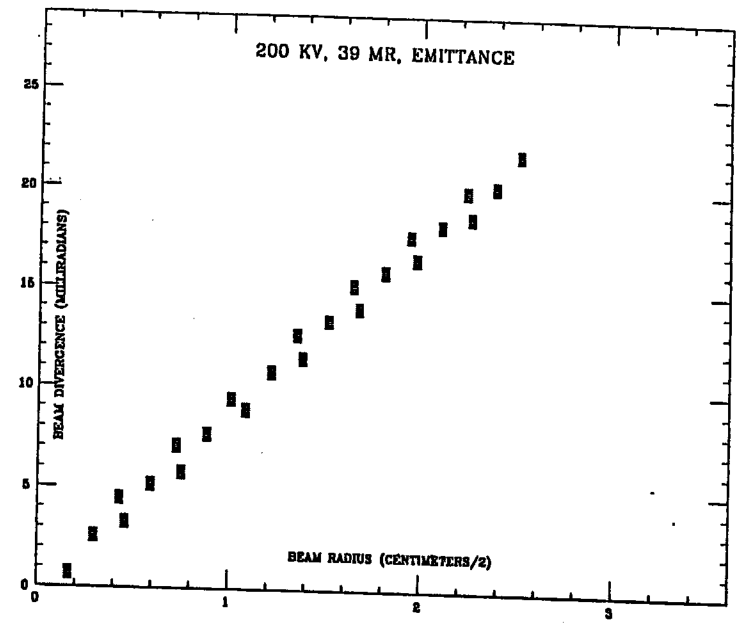


Figure 13 – Final phase space plot of the H^- beam as it leaves the preac. Preac voltage is 200 KV, initial H^- beam is assumed to have 39 milliradians of initial divergence and finite emittance.

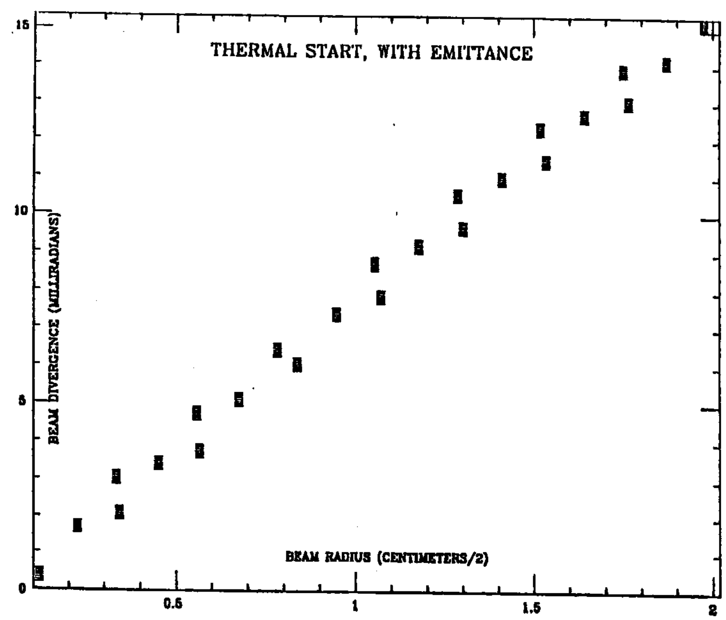


Figure 15 – Final phase space plot of the thermally emitted H^+ beam as it leaves the preac. Preac voltage is 760 KV.